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Declaration

I, Michihiko Matsuba, President of Fukuyama Sangyo Honyaku Center, Ltd., of 16-3, 2-chome, Nogami-cho, Fukuyama, Japan, do solemnly and sincerely declare that I understand well both the Japanese and English languages and that the attached document in English is a full and faithful translation, of the copy of Japanese Patent Application No. 2002-190599 filed on June 28, 2002.

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[Title of the invention] AUTOMATIC SURVEY SYSTEM

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[TITLE OF DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION] AUTOMATIC SURVEY SYSTEM

[WHAT IS CLAIMED IS;]

[Claim 1] An automatic survey system, comprising:

a survey means for conducting a survey;

a co-line calculation means which determines, as a co-line, a straight line that regulates collinear conditions with respect to points arbitrarily specified in a survey image of a survey site having a known positional relationship with the survey means;

a collimation direction control means which controls the survey means to move in a collimation direction of the survey means along the co-line; and

an object point search means that searches for positions of object points to be surveyed at which the object points are on the co-line by conducting a survey in the collimation direction by using the survey means during driving of the collimation direction control means, wherein

the positions searched by the object point search means are object points corresponding to the specified points on the survey image.

[Claim 2] The automatic survey system according to Claim 1, wherein the automatic survey system further comprises a

positional relationship calculation means that calculates a positional relationship between the survey means and the survey image, and the positional relationship is calculated from a relationship between survey data of three or more arbitrary set reference points and positions of the reference points on the survey image.

[Claim 3] The automatic survey system according to Claim 2, wherein the automatic survey system further comprises an input means for specifying positions on the survey image, and the positions of the reference points are determined by specifying arbitrary positions on the survey image by the input means.

[Claim 4] The automatic survey system according to Claim 1, wherein the automatic survey system further comprises an input means for specifying positions on the survey image, and arbitrary points on the survey image to become targets to be searched for by the object point search means are specified by the input means.

[Claim 5] The automatic survey system according to Claim 4, wherein an arbitrary straight line or curved line on the survey image can be specified by the input means, and the object point search means searches for a plurality of points along the straight line or curved line.

[Claim 6] The automatic survey system according to Claim 4,

wherein an arbitrary closed curve on the survey image can be specified by the input means, and the object search means searches for a plurality of points within the closed curve.

[Claim 7] An automatic survey system, comprising:

a positional relationship calculation means that calculates a positional relationship between a coordinate system as a reference of survey data of survey points and a survey image of a survey site including the survey points;

an associating means that associates the survey point survey data with position data of positions on the survey image corresponding to the survey points;

an input means for specifying positions of survey points on the survey image; and

a collimation direction control means that controls a collimation direction of a survey means based on the positions of the survey points on the survey image specified by the input means.

[Claim 8] The automatic survey system according to Claim 7, wherein the survey image is taken by setting a projection center of an imaging optical system at a position optically equivalent to a collimation origin of the survey means, the collimation direction control means calculates angle data of a collimation point in the coordinate system based on two-dimensional position

data of the collimation point whose position is specified on the survey image by the input means and external orientation elements of an imaging device that has taken the survey image, and collimates the survey means in a direction corresponding to the angle data.

[Claim 9] The automatic survey system according to Claim 8, wherein when the survey point survey data is predetermined geographic data including set survey points, the survey points are indicated on the survey image based on three-dimensional position data of the survey points, a survey point specified by the input means among the survey points is set as the collimation point and collimation of the survey means is controlled.

[Claim 10] The automatic survey system according to Claim 9, wherein the indication of the survey point on the survey image after collimation is changed.

[Claim 11] The automatic survey system according to Claim 7, wherein the collimation point is indicated on the survey image.

[Claim 12] The automatic survey system according to Claim 11, wherein after collimation of the survey means to the collimation point, the indication of the collimation point on the survey image is changed.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Field of the art]

The present invention relates to a survey system using a surveying instrument.

[0002]

[Prior Arts]

Normally, a survey is made by a pair of operators, including an operator who holds a reflecting target such as a prism at a survey point to be surveyed, and an operator who operates the surveying instrument. In such a surveying work, the operator who holds the target must move his location for each survey point, and each time, the operator who operates the surveying instrument must perform a collimating operation to the target. Therefore, the surveying work is very troublesome and high in cost since requires manpower and time. Recently, a non-prism type surveying instrument that does not require a reflecting target such as a prism is also available. The non-prism type surveying instrument does not require the operator who holds the target and can conduct a survey by only an operator who operates the surveying instrument, whereby making the work efficient. However, even with the non-prism type surveying instrument, the operator must perform a collimating operation of the surveying instrument for each survey point. Particularly,

when the number of set points to be surveyed is large as in such a case where the capacity of a depression into which sediment is deposited is estimated, the work takes a long time and places a great load on the operator.

[0003]

[Objects to be Solved by the Invention]

An object of the invention is to improve the working efficiency in a survey. More specifically, the object of the invention is to easily and efficiently associate survey data obtained by a surveying instrument with image data obtained by a camera, control collimation of the surveying instrument based on the image data, and conduct automatic surveys.

[0004]

[Means for Solving the Problem]

An automatic survey system of the invention comprises: a survey means for conducting a survey; a co-line calculation means which determines, as a co-line, a straight line that regulates collinear conditions with respect to points arbitrarily specified in a survey image of a survey site having a known positional relationship with the survey means; a collimation direction control means which controls the survey means to move in a collimation direction of the survey means along the co-line; and an object point search means that searches

for positions of object points to be surveyed at which the object points are on the co-line by conducting a survey in the collimation direction by using the survey means during driving of the collimation direction control means, wherein the positions searched by the object point search means are object points corresponding to the specified points on the survey image.

[0005]

Preferably, the automatic survey system further comprises a positional relationship calculation means that calculates a positional relationship between the survey means and the survey image, and the positional relationship is calculated from a relationship between survey data of three or more arbitrary set reference points and positions of the reference points on the survey image. Thereby, the positional relationship between the survey means and the survey image can be easily obtained, so that automatic surveys can always be easily conducted. To more easily obtain the positional relationship, preferably, the automatic survey system comprises an input means for specifying positions on the survey image, and the positions of the reference points are determined by specifying arbitrary positions on the survey image by the input means.

[0006]

In addition, preferably, an arbitrary point on the survey

image as an object to be searched for by the object point search means can be specified with the input means. In this case, an arbitrary straight line or curved line on the survey image can be specified by the input means, and the object point search means searches for a plurality of points along the straight line or curved line. Or, an arbitrary closed curve on the survey image can be specified by the input means, and the object search means searches for a plurality of points within the closed curve. Thereby, an operator can automatically obtain a large amount of survey data regarding a curved line and a region only by specifying the curved line (straight line) and region, whereby making the survey work remarkably efficient.

[0007]

Furthermore, an automatic survey system of the invention, comprises: a positional relationship calculation means that calculates a positional relationship between a coordinate system as a reference of survey data of survey points and a survey image of a survey site including the survey points; an associating means that associates the survey point survey data with position data of positions on the survey image corresponding to the survey points; an input means for specifying positions of survey points on the survey image; and a collimation direction control means that controls a collimation direction of a survey

means based on the positions of the survey points on the survey image specified by the input means.

[0008]

The survey image is taken by setting a projection center of an imaging optical system at a position optically equivalent to a collimation origin of the survey means (for example, mechanical center of TS or ETH), the collimation direction control means calculates angle data of a collimation point in the coordinate system based on two-dimensional position data of the collimation point whose position is specified on the survey image by the input means and external orientation elements of an image pickup device that has taken the survey image, and collimates the survey means in a direction corresponding to the angle data. In this case, the horizontal angle and the elevation angle can be directly calculated from the image coordinates of the collimation point on the survey image, whereby making the processing simpler.

[0009]

When survey data of survey points are known, for example, the survey points are indicated on a survey image based on three-dimensional position data of the survey points, and a survey point specified by the input means among these survey points is set as a collimation point and collimation of the

survey means is controlled. Thereby, even in the case of collimation to a survey set point whose survey data is provided in advance for survey set operations, or in the case of re-collimation to a survey point that has already been surveyed, the survey means can be easily collimated to the target survey point.

[0010]

Furthermore, preferably, the automatic survey system indicates the collimation point on the survey image, and preferably, after collimation of the survey means to the collimation point, the indication of the collimation point on the survey image is changed. Likewise, it is preferable that the indication of the survey point on the survey image is changed after collimation. Thereby, the operator can easily visually recognize that the survey means has been collimated to a target survey point.

[0011]

[Preferred Embodiments of the Invention]

Hereinafter, an embodiment of the invention is explained with reference to the drawings.

Fig. 1 is a block diagram showing an outline of a survey system using a surveying instrument and a camera according to an embodiment of the invention.

[0012]

The surveying instrument is, for example, a total station, which has a collimating telescope 17 for collimation to a survey point. The collimating telescope 17 has a horizontal axis Lh for elevating the collimating telescope to measure an elevation angle θp and a vertical axis Lp for rotating the collimating telescope horizontally to measure a horizontal angle θh, and is rotatable around these axes. The horizontal axis Lh and the vertical axis Lp cross at right angles at a point O_S (hereinafter, referred to as a collimation origin O_S), and the optical axis (collimation line) of the collimating telescope 17 pass through the collimation origin O_S. The optical axis LN_O is divided into two by the half mirror 18, and one is guided to an eyepiece lens and the other is guided to a rangefinding portion 11.

[0013]

The rangefinding portion 11 detects a slope distance, etc., to a collimated survey point by, for example, an electro-optical range finder, and an angle measuring/angle controlling portion 12 detects a horizontal angle θh and an elevation angle θp in this case. The collimating telescope 17 can be rotated around the horizontal axis Lh and the vertical axis Lp by an unillustrated stepping motor, etc., and these rotations are controlled by the angle measuring/angle controlling portion

12.

[0014]

The rangefinding portion 11 and the angle measuring/angle controlling portion 12 are respectively connected to a system control circuit 13, and are controlled based on an instruction from the system control circuit 13. For example, the rangefinding portion 11 performs rangefinding based on an instruction from the system control circuit 13, and transmits a measured value to the system control circuit 13. On the other hand, the angle measuring/angle controlling portion 12 always measures the angle and transmits the measured value to the system control circuit 13 in response to a request from the system control circuit 13, and drives the stepping motor to control the rotations around the horizontal axis Lh and the vertical axis Lp. The measured values of the detected slope distance, horizontal angle, and elevation angle, etc., are processed by the system control circuit 13. To the system control circuit 13, a switch group14, a display 15 (for example, LCD), an interface circuit 16, etc., are connected in addition.

[0015]

To the interface circuit 16, a computer 40 such as a notebook personal computer is connected via an interface cable. Namely, the surveying instrument 10 can transmit survey data, etc.,

to the computer 40 via the interface cable. The surveying instrument 10 can also be controlled based on a control signal from the computer 40, and for example, the collimation direction of the collimating telescope 17 (horizontal angle θh and elevation angle θp) can be controlled from the computer 40. The interface circuit 16 can also be connected to a peripheral device such as a data collector (not shown).

[0016]

The computer 40 mainly comprises, centering around a CPU 41, a recording medium 42 such as a hard disk, DVD, MO, or IC card, an input device such as a mouse 43 and a keyboard 44, an image display device (monitor) 45 such as an LCD or CRT, and an interface circuit 46. As described above, the interface 46 is connected to the interface circuit 16 of the surveying instrument 10 via the interface cable. The interface circuit 46 is connectable to, for example, a digital still camera 20. Namely, an image taken by the digital still camera 20 is transmitted to the computer 40 as digital image data and recorded on the recording medium 42 via the interface circuit 46.

[0017]

Next, a single photograph orientation processing in a survey system of the embodiment is explained with reference to Fig. 1, Fig. 2, and Fig. 3. Fig. 2 is a flowchart of single photograph

orientation processing in the survey system of the embodiment, and Fig. 3 is a conceptual diagram of arrangement of the surveying instrument and a digital still camera when a survey view of a survey site is taken by the digital still camera.

[0018]

First, at Step S101, an operator takes an image of the survey view of a survey site with the digital still camera (DSC) 20, transmits the taken digital image to the computer 40 via the interface cable, etc., and records it on the recording medium 42. The taken digital image (survey image) includes a plurality of survey points to be surveyed.

[0019]

At Step S102, the taken survey image is displayed on, for example, a monitor 45 of the computer 40. In this case, a plurality of points (pixels) in the displayed survey image are selected by using a pointing device such as a mouse 43 by the operator. Thereby, object points in the real space corresponding to the thus selected pixels are specified as reference points P_i (i=1, 2…, n) (reference points are survey points to be used for calculating a positional relationship between the survey image and survey data). The positions of image points P_i' on the survey image corresponding to the respective specified reference points P_i are calculated as two-dimensional image coordinates

(xp_i', yp_i'). The image coordinate system is a two-dimensional coordinate system that has an origin set at the upper left of the image and is positive downward of the y' axis. The number n of reference points is, for example, 11 or more, three-dimensionally arranged.

[0020]

At Step S103, a slope distance and angles (elevation, horizontal) of each reference point P_i specified at Step S102 are measured by the operator by using the surveying instrument 10, and the measured values are transmitted to the interface circuit 46 of the computer 40 via the interface circuit 16. The CPU 41 calculates the three-dimensional coordinates (Xp_i, Yp_i, Zp_i) of each reference point P_i in a predetermined survey coordinate system. In this case, the survey coordinates (Xp_i, Yp_i, Zp_i) of the reference points P_i are respectively associated with the image coordinates (xp_i', yp_i') of the image points P_i',. In the embodiment, in the survey coordinate system, for example, the collimation origin O_S of the surveying instrument 10 is set as an origin, however, it is also possible that an absolute coordinate regulated by the Geographical Survey Institute or a coordinate system arbitrarily determined at the survey site is used. In addition, it is also allowed that the surveying instrument 10 calculates the survey coordinates and transits

these to the computer 40.

[0021]

At Step S104, as described later, external orientation elements that indicate the position and inclination of the digital still camera 20 when taking the survey image and internal normal position elements for correcting deviations of co-line conditions due to lens distortion or eccentricity of a principal point from the image center are calculated by, for example, the spatial resection backward intersection method from association between survey coordinates with respect to the respective reference points P_i and image coordinates. Namely, a position (X_O, Y_O, Z_O) of the origin O_C of the three dimensional camera coordinate system fixed to the digital still camera 20 in the survey coordinate system and the rotation angles (ω, ϕ, κ) around the x axis, y axis, and z axis of the camera coordinate system when taking the image are calculated as external orientation elements, and camera internal normal position elements (f: distance from the lens projection center to the image surface (image distance); D_2, D_4, and D_6: distortion two-dimensional, four-dimensional, and six-dimensional components; P_1 and P_2: distortion asymmetrical components; and X_C and Y_C: eccentric amounts of the principal point from the image center) are calculated. Thereby, the projection

relationship between the image coordinates and the survey coordinates is established. When the internal normal position elements are set to (f, D_2, D_4, D_6, P_1, P_2, X_C, and Y_C) described above, the number of reference points necessary for calculating the external orientation elements and internal normal position elements is 7 or more. Among these, the number of reference points necessary for calculating the external orientation elements (X_O, Y_O, Z_O, ω, ϕ, κ) is 3 or more. In the embodiment, 11 (or more) points are specified as reference points for external orientation and internal orientation.

[0022]

The camera coordinate system is a right-handed coordinate system having an origin O_C set at the lens center (projection center), and its x axis and y axis are in parallel to the s′ axis and the t′ axis of a screen coordinate system, and the z axis is perpendicular to the imaging plane and defined toward the image surface. Namely, points on an imaging surface are expressed by (x, y, f). Herein, the screen coordinate system is a two-dimensional coordinate system on the imaging surface having an origin set at the principal point, and the s′ axis corresponds to the horizontal line direction of an image pickup device 21 and the t′ axis corresponds to the vertical line direction (see Fig. 4).

[0023]

After the processings of Step S101 through Step S104, the single photograph orientation processing of the embodiment is ended. It is also possible that a survey image taken before is used instead of taking an image of a survey site at Step S101. In the embodiment, the single photograph orientation processing is explained with reference to the flowchart of Fig. 2, however, it is also possible that a survey of the reference points at Step S103 is made first and then Step S101 and Step S102 are performed. As reference point survey data, data surveyed before and predetermined geographic data (including triangulation points provided by the Geographical Survey Institute and geographic data of maps avalable on the market) can be used.

[0024]

Next, with reference to Fig. 4 and Fig. 5, the principle of the method of calculating external orientation elements and internal normal position elements by means of the spatial resection backward intersection method of the digital still camera 20 in the embodiment (Step S104) is explained.

[0025]

Fig. 4 is a schematic diagram of the relationship between three reference points P_1, P_2, and P_3 and image points P_1', P_2',

and P_3' on the imaging surfaces S of these. Fig. 5 is a flowchart of a program of the spatial resection backward intersection method to calculate the external orientation elements (X_O, Y_O, Z_O, ω, ϕ, κ) and camera internal normal position elements (f, D_2, D_4, D_6, N_1, N_2, X_C, Y_C) that indicate the position and inclination of the digital still camera 20 at Step S104 of Fig. 2, and for calculating these, successive approximation method using the least squares method is used. In the embodiment, as described above, the number of reference points is any number as long as it is equal to or more than 7, however, herein, the case where 11 reference points are specified is explained as an example. Fig. 4 shows only three points P_1, P_2, and P_3 of these points.

[0026]

First, at Step S201, as approximate values to external orientation elements (X_O, Y_O, Z_O, ω, ϕ, κ) and internal normal position elements (f, D_2, D_4, D_6, N_1, N_2, X_C, Y_C) indicating the position and inclination of the camera, appropriate initial values (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G) and (f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}) are provided. Next, at Step S202, by using the provided external orientation elements (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G) and internal normal position elements (f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}), approximate image coordinates (xp_{Gi}', yp_{Gi}') of image

points P_i' corresponding to the respective reference points P_i are calculated from the survey coordinates (Xp_i, Yp_i, Zp_i) of the 11 reference points P_i (i=1, 2…, 11).

[0027]

Namely, the coordinates (xp_i, yp_i, zp_i) of the reference points P_i (i=1, 2…, 11) in the camera coordinate system are calculated by the following equation (1) from the coordinates (Xp_i, Yp_i, Zp_i) in the survey coordinate system, so that by substituting the approximate external orientation elements (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G) and the survey coordinates (Xp_i, Yp_i, Zp_i) of the reference points P_i into the equation (1), the approximate camera coordinates (xp_{Gi}, yp_{Gi}, zp_{Gi}) of the reference points P_i can be calculated.

[Numerical formula 1]

$$\begin{pmatrix} xp_i \\ yp_i \\ zp_i \end{pmatrix} = \begin{pmatrix} T_{11} & T_{12} & T_{13} \\ T_{21} & T_{22} & T_{23} \\ T_{31} & T_{32} & T_{33} \end{pmatrix} \begin{pmatrix} Xp_i - X_0 \\ Yp_i - Y_0 \\ Zp_i - Z_0 \end{pmatrix} \quad (1)$$

Herein, the matrix $\{T_{jk}\}$ is a rotating matrix, and each component T_{jk} is expressed by, for example, the following equations

$T_{11} = \cos\phi \bullet \cos\kappa$

$T_{12} = \cos\omega \bullet \sin\kappa + \sin\omega \bullet \sin\phi \bullet \cos\kappa$

$T_{13} = \sin\omega \bullet \sin\kappa - \cos\omega \bullet \sin\phi \bullet \cos\kappa$

$T_{21} = -\cos\phi \bullet \sin\kappa$

T_{22}= cosω • cosκ − sinω • sinφ • sinκ

T_{23}= sinω • cosκ + cosω • sinφ • sinκ

T_{31}= sinφ

T_{32}= −sinω • cosφ

T_{33}= cosω • cosφ

[0028]

The screen coordinates (sp_i', tp_i') before being corrected by using the internal normal position elements of image points P_i' corresponding to the reference points P_i are calculated by the following equations (2) by using the external orientation elements (X_O, Y_O, Z_O, ω, φ, κ) and the camera coordinates (xp_i, yp_i, zp_i) of the reference points P_i from collinear conditions in that the taken reference points, projection center, and image points thereof are on the same straight line.

[Numerical formula 2]

$$sp_i' = f\,\frac{xp_i}{zp_i} = f\,\frac{T_{11}(Xp_i - X_0) + T_{12}(Yp_i - Y_0) + T_{13}(Zp_i - Z_0)}{T_{31}(Xp_i - X_0) + T_{32}(Yp_i - Y_0) + T_{33}(Zp_i - Z_0)}$$

$$tp_i' = f\,\frac{yp_i}{zp_i} = f\,\frac{T_{21}(Xp_i - X_0) + T_{22}(Yp_i - Y_0) + T_{23}(Zp_i - Z_0)}{T_{31}(Xp_i - X_0) + T_{32}(Yp_i - Y_0) + T_{33}(Zp_i - Z_0)} \quad (2)$$

[0029]

The screen coordinates (sp_i', tp_i') before being corrected are influenced by distortion, etc., however, these are corrected by substituting the screen coordinates (sp_i', tp_i') of the

respective image points P_i' and approximate internal normal position elements (f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}) into the equations (3). Namely, by the equations (3), the approximate screen coordinates (scpi', tcpi') after being corrected are calculated.

[Numerical formula 3]

$$R2=sp_i^{i2}+tp_i^{i2}$$

$$scp_i'=sp_i'(1+D_2R^{2+}D_4R^{4+}D_6R^6)+(R^2+2sp_i'^2)N_1+2sp_i'tp_i'N_2+X_C$$

$$tcp_i'=tp_i'(1+D_2R^{2+}D_4R^{4+}D_6R^6)+2sp_i'tp_i'N_1+(R^2+2tp_i'^2)N_2+Y_C \quad (3)$$

[0030]

The approximate image coordinates (xp_{Gi}', yp_{Gi}') of the image points P_i' are calculated by substituting the corrected approximate screen coordinates (scp_{Gi}', tcp_{Gi}') into the following equations (4).

[Numerical formula 4]

$$xp_i'= scp_i'/(-P_x)+W/2$$

$$yp_i'= tcp_i'/P_y+H/2 \quad (4)$$

Herein, Px and Py indicate horizontal and vertical pixel pitches of the CCD, respectively, and W and H indicate the numbers of pixels in the horizontal direction and the vertical direction of the image.

[0031]

At Step S203, a merit function Φ for judging whether the

approximately provided external orientation elements (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G) and internal normal position elements (f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}) are appropriate is calculated. The merit function Φ is defined by, for example, the equation (5).

[Numerical formula 5]

$$\Phi = \sum_{i=1}^{11} \left\{ (xp_i{}^i - xp_{Gi}{}^i)^2 + (yp_i{}^i - yp_{Gi}{}^i)^2 \right\} \quad (5)$$

Namely, in the embodiment, the merit function Φ corresponds to the square of the distance between image coordinates (xp_i', yp_i') of the image points P_i' of the reference points P_i specified on the survey image and approximate image coordinates (xp_{Gi}', xp_{Gi}') of image points P_i' determined from the survey coordinates (Xp_i, Yp_i, Zp_i) of the reference points P_i determined by a survey and the approximately provided external orientation elements (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G) and internal normal position elements (f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}).

[0032]

Next, at Step S204, it is judged whether the merit function Φ is smaller than a predetermined value. Namely, it is judged whether approximate image coordinates (xp_{Gi}', yp_{Gi}') of image points P_i' according to the approximately provided external orientation elements (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G) and internal normal position elements (f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}) are sufficiently close to the image coordinates (xp_i', yp_i') of image

points P_i' of the reference points P_i specified on the survey image. When Φ is smaller than the predetermined value, this processing is ended, and the currently provided external orientation elements (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G) and internal normal position elements (f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}) are used as external orientation elements and internal normal position elements indicating the camera position and inclination when it takes the survey image.

[0033]

On the other hand, when it is judged Φ is as equal or larger than the predetermined value at Step S204, correction amounts (δX, δY, δZ, $\delta\omega$, $\delta\phi$, $\delta\kappa$, δf, δD_2, δD_4, δD_6, δN_1, δN_2, δX_C, δY_C) for the approximately provided external orientation elements (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G) and internal normal position elements (f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}) are calculated by, for example, the least squares method at Step S205. Namely, (scp_i', tcp_i') of the equations (3) are substituted for (sp_i', tp_i') as collinear conditions in the equations (2), Taylor-expanded around the approximate external orientation elements (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G) and internal normal position elements (f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}), and linearized by omitting high-order terms. In this linearized equation, a normal equation in that the correction amounts (δX, δY, δZ, $\delta\omega$, $\delta\phi$, $\delta\kappa$, δf, δD_2, δD_4, δD_6,

δN_1, δN_2, δX_C, δY_C) are unknown amounts is created to calculate proper correction amounts (δX, δY, δZ, $\delta\omega$, $\delta\phi$, $\delta\kappa$, δf, δD_2, δD_4, δD_6, δN_1, δN_2, δX_C, δY_C).

[0034]

At Step S206, based on the correction amounts (δX, δY, δZ, $\delta\omega$, $\delta\phi$, $\delta\kappa$, δf, δD_2, δD_4, δD_6, δN_1, δN_2, δX_C, δY_C) calculated at Step S205, the approximate external orientation elements (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G) and internal normal position elements (f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG}) are updated. Namely, the respective values of (X_{GO}, Y_{GO}, Z_{GO}, ω_G, ϕ_G, κ_G, f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG},) are substituted with ($X_{GO}+\delta X$, $Y_{GO}+\delta Y$, $Z_{GO}+\delta Z$, $\omega_G+\delta\omega$, $\phi_G+\delta\phi$, $\kappa_G+\delta\kappa$, $f_G+\delta f$, $D_{2G}+\delta D_2$, $D_{4G}+\delta D_4$, $D_{6G}+\delta D_6$, $N_{1G}+\delta N_1$, $N_{2G}+\delta N_2$, $X_{CG}+\delta X_C$, $Y_{CG}+\delta Y_C$), whereby the camera position and internal normal positions are updated. Thereafter, the process returns to Step S202, and Steps S202 through S206 are repeatedly performed until Φ is judged as smaller than the predetermined value at Step S204.

[0035]

Next, with reference to Fig. 1, Fig. 6, and Fig. 7, the outline of the automatic survey processing in the survey system of the embodiment is explained.

[0036]

Fig. 6 shows a survey image of a survey site displayed on

the monitor 45. The operator determines a region (survey region) A to be surveyed on the survey image by operating a mouse cursor by, for example, the mouse 43. As shown in Fig. 7, the computer 40 calculates a straight line (hereinafter, referred to as co-line) LN_C with respect to an arbitrary pixel (image point Q_6' corresponding to object point Q_6) within the survey region A. The surveying instrument 10 conducts a survey at predetermined intervals (for example, points R_1 through R_5) while scanning the co-line LN_C (movement while intersecting the collimation line LN_O with the co-line LN_C), and the object point Q_6 is searched by referring to survey coordinates obtained when the surveying instrument 10 is directed toward the respective points R_j ($j=1$, $2\ldots$, 6). This is performed for all pixels in, for example, the survey region A. It is also possible that the survey region A is automatically divided into grids at arbitrary intervals (for example, equal intervals) and the search is made for each grid point. It is also possible that a curve B is specified and the curve is automatically divided at arbitrary intervals (for example, equal intervals). The survey region A and the curve B are both specified by a person who conducts a measurement. The arbitrary intervals can be set to equal intervals by angles of the surveying instrument. The survey region A and the curve B can be created by detecting an arbitrary specified color range

or brightness range by applying image processing to the survey image, or created by edge detection, etc.

[0037]

For example, when the surveying instrument 10 is directed toward the point R_2 on the co-line LN_C, the position of the object point Q_2 out of the survey region is measured by the surveying instrument 10. Therefore, by substituting the external orientation elements (X_O, Y_O, Z_O, ω, ϕ, κ) and internal normal position elements (f, D_2, D_4, D_6, N_1, N_2, X_C, Y_C) calculated by the single photograph orientation processing and the measured survey coordinates (X_{q2}, Y_{q2}, and Z_{q2}) of the object point Q_2 into the equations (1) through (4), the image coordinates (x_{q2}', y_{q2}') on the survey image corresponding to the object point Q_2 are calculated. The object point Q_2 is different from the object point Q_6 corresponding to the specified image point Q_6', so that the image coordinates (x_{q2}', y_{q2}') corresponding to the measured object point Q_2 are different from the image coordinates (x_{q6}', y_{q6}') of the object point Q_6'.

[0038]

On the other hand, the point R_6 on the co-line LN_C is an intersection between the co-line LN_C and an object within the survey region, and matches the object point Q_6. Namely, the image coordinates calculated from the survey coordinates

measured when the surveying instrument is directed toward the point R_6 are equal to the image coordinates (x_{q6}', y_{q6}') of the specified image point Q6'. Therefore, a survey is made along the co-line with respect to the arbitrarily specified pixel (in the survey region A in the embodiment), and by searching for an object point which matches image coordinates calculated from these surveyed coordinates with image coordinates of the specified pixel, the survey of the object point corresponding to the arbitrary pixel on the survey image can be automatically conducted.

[0039]

Details of the automatic survey processing operations of the embodiment are explained with reference to Fig. 8 through Fig. 11.

[0040]

Fig. 8 is a flowchart of the program of the whole of the automatic survey processing operations, and the program is executed by the CPU 41. The automatic survey processing operations of Fig. 8 are performed after the single photograph orientation processing for the survey image is finished, and the external orientation elements and internal normal position elements of the digital still camera 20 when it takes the survey image are determined in advance. At Step S301, a survey region

A determined on the survey image of the monitor 45 by the operator with a mouse 43 is acquired, and pixel numbers (1 through N, N: total number of pixels in the survey region A) are assigned to all pixels in the survey region A.

[0041]

At Step S302, the pixel number i is set to 1, and the processings of Step S303 through Step S306 are repeated until i reaches N. Namely, at Step S303, a survey is automatically made by the surveying instrument 10 along a co-line of image coordinates (x_i', y_i') corresponding to the pixel number i, and image coordinates corresponding to the measured survey coordinates are compared with image coordinates (x_i', y_i') of the pixel number i, whereby the position of an object point corresponding to the pixel of the pixel number i is searched and surveyed (object point search processing). The details of the object point search processing are explained later.

[0042]

At Step S304, survey data with respect to the pixel (x_i', y_i') detected by the object point search processing of Step S303 is recorded on the recording medium 42, etc. At Sep S305, it is judged whether the pixel number i is larger than the total pixel number N. Namely, it is judged whether the project point search processing has been finished for all pixels in the survey

region A. When it is judged that i is not larger than N, i is incremented by 1 at Step S306, and the process returns to Step S303 again. On the other hand, when it is judged that i is larger than N, this automatic survey processing operation is ended.

[0043]

Fig. 9 is a flowchart of the details of the object point search processing of Step S303. At Step S401, a unit co-line vector (r_{ix}, r_{iy}, r_{iz}) on a co-line LN_C corresponding to image coordinates (x_i', y_i') is calculated (unit co-line vector calculation processing). In the object point search processing, a survey is made by collimating the surveying instrument 10 to virtual collimation points R_j on the co-line LN_C arranged at predetermined intervals. At Step S402, a distance L from the camera coordinate origin O_C (X_O, Y_O, Z_O) with respect to the virtual collimation points R_j on the co-line LN_C is set to an initial distance L_a.

[0044]

At Step S403, from the unit co-line vector (r_{ix}, r_{iy}, r_{iz}) calculated at Step S401 and the distance L, survey coordinates (X_{Rj}, Y_{Rj}, Z_{Rj}) of virtual collimation points R_j are calculated by the following equations:

$X_{Rj}=X_O+r_{ix} \bullet L$

$Y_{Rj}=X_O+r_{iy} \bullet L$

$Z_{Rj}=X_O+r_{iz} \bullet L$ (6)

and horizontal angles θh and elevation angles θp for collimating the collimating telescope 17 to the virtual collimation points R_j are calculated by the following equations (7) and (8).

[Numerical formula 6]

$$\theta h = \begin{cases} \sin^{-1}\left(\dfrac{\dfrac{X_{Ri}}{\sqrt{X_{Ri}^2 + Y_{Ri}^2 + Z_{Ri}^2}}}{\cos(\sin^{-1}\dfrac{Y_{Ri}}{\sqrt{X_{Ri}^2 + Y_{Ri}^2 + Z_{Ri}^2}}}\right) & (Z_{Ri} \geq 0) \\ \pi - \sin^{-1}\left(\dfrac{\dfrac{X_{Ri}}{\sqrt{X_{Ri}^2 + Y_{Ri}^2 + Z_{Ri}^2}}}{\cos(\sin^{-1}\dfrac{Y_{Ri}}{\sqrt{X_{Ri}^2 + Y_{Ri}^2 + Z_{Ri}^2}}}\right) & (Z_{Ri} < 0) \end{cases} \quad (7)$$

[Numerical formula 7]

$$\theta p = \sin^{-1}\left(\frac{Y_{Ri}}{\sqrt{X_{Ri}^2 + Y_{Ri}^2 + Z_{Ri}^2}}\right) \quad (8)$$

As shown in Fig. 10, in the equations (7) and (8), the origin of the survey coordinate system is at the collimation origin O_S, and when θp=θh=0, the X axis matches the horizontal axis Lh, the Y axis matches the vertical axis Lp, and the Z axis matches the collimation line (optical axis) LN_O. In this case, the surveying instrument 10 directs the collimation line (optical axis) LN_O of the collimating telescope 17 toward (θh,

θp) based on a signal instruction from the computer 40.

[0045]

At Step S404, a survey is conducted in the collimation direction of Step S403. Based on survey data of the object point Q_i corresponding to the virtual collimation point R_i surveyed in actuality by the survey, the survey coordinates (X_{Qi}, Y_{Qi}, Z_{Qi}) are calculated. At Step S405, image coordinates of the object point Q_i (x_{Qi}', y_{Qi}') corresponding to the survey coordinates (X_{Qi}, Y_{Qi}, Z_{Qi}) of the object point Q_i are calculated by using the external orientation elements (X_O, Y_O, Z_O, ω, ϕ, κ) and internal normal position elements (f, D_2, D_4, D_6, N_1, N_2, X_C, Y_C).

[0046]

At Step S406, it is judged whether the image coordinates (x_{Qi}', y_{Qi}') corresponding to the object point Q_i match the image coordinates (x_i', y_i') of the co-line LN_C. For example, when the distance between the image coordinates (x_{Qi}', y_{Qi}') and the image coordinates (x_i', y_i') is within a predetermined value, it is judged that the image coordinates (x_{Qi}', y_{Qi}') corresponding to the object point Q_i match the image coordinates (x_i', y_i') of the co-line LN_C. In this case, at Step S407, the calculated survey coordinates (X_{Qi}, Y_{Qi}, Z_{Qi}) of the object point Q_i are set as survey coordinates corresponding to the pixel (x_i', y_i')

of the pixel number i, and then the object search processing is ended. On the other hand, when it is judged that they do not match each other, at Step S408, the distance L is updated to L+ΔL, and the processings of the step S403 and subsequent steps are repeated. ΔL is an increment amount of the distance L, and is determined depending on the measurement accuracy and measuring time.

[0047]

Next, with reference to Fig. 11, unit co-line vector calculation processing to be executed at Step S401 is explained. Fig. 11 is a flowchart of the unit co-line vector calculation processing.

[0048]

In the embodiment, the unit co-line vector is calculated by using the least squares method. Namely, in the unit co-line vector calculation processing of the embodiment, an arbitrary unit vector (r_{Gix}, r_{Giy}, r_{Giz}) is set as an approximate unit co-line vector with respect to the pixel (x_i', y_i'), and at Step S501, image coordinates (x_{Gi}', y_{Gi}') corresponding to the survey coordinates (X_O+r_{Gix}, Y_O+r_{Giy}, Z_O+r_{Giz}) indicated by the end of the unit vector (r_{Gix}, r_{Giy}, r_{Giz}) starting from the camera coordinate origin O_C (X_O, Y_O, Z_O) are calculated from the equations (1) through (4) by using the external orientation elements (X_O,

Y_O, Z_O, ω, ϕ, κ) and internal normal position elements (f, D_2, D_4, D_6, N_1, N_2, X_C, Y_C).

[0049]

At Step S502, a merit function $\Phi = (x_i' - x_{Gi}')^2 + (y_i' - y_{Gi}')^2$ with respect to the image coordinates (X_{Gi}, Y_{Gi}, Z_{Gi}) calculated at Step S501 is calculated. At Step S503, it is judged whether the value of the merit function Φ is smaller than a predetermined value. When the value of the merit function Φ is judged as being smaller than the predetermined value, the unit vector (r_{Gix}, r_{Giy}, r_{Giz}) is set as the unit co-line vector (r_{ix}, r_{iy}, r_{iz}) with respect to the pixel of the pixel number i at Step S504, and the unit co-line vector calculation processing is ended.

[0050]

On the other hand, at step S503, when it is judged that the merit function Φ is not smaller than the predetermined value, correction amounts (δr_{ix}, δr_{iy}, δr_{iz}) for the unit vector (r_{Gix}, r_{Giy}, r_{Giz}) approximately provided at Step S505 are determined by, for example, the least squares method. The approximate unit vector is updated to the unit vector ($r_{Gix}+\delta r_{ix}$, $r_{Giy}+\delta r_{iy}$, $r_{Giz}+\delta r_{iz}$). Thereafter, the process returns to Step S501, and Steps S501 through S505 are repeatedly executed until Φ is judged as being smaller than the predetermined value at Step S503.

[0051]

The capacity, etc., of the survey region are calculated from the survey data of the survey region obtained by the automatic survey processing operations. It is also possible that only the outer periphery of the specified survey region is automatically surveyed to calculate the area and outer peripheral length, etc., of the survey region.

[0052]

As described above, according to the embodiment, a survey point specified on the survey image can be collimated by using the surveying instrument and automatically surveyed. In a surveying instrument 10 having a CCD inside, although this is not shown, a survey point is roughly collimated by the surveying instrument 10 in response to an instruction from the survey image, control is performed so that the hair center comes to the point specified on the CCD image inside the surveying instrument 10 at a magnification higher than the survey image, whereby detailed collimation can be performed. In the embodiment, by determination of a survey region on a survey image by an operator, the surveying instrument can automatically conduct the survey within the region, so that the survey working efficiency is remarkably improved.

[0053]

When a lens with a long focal length such as a telephoto

lens is used for taking a survey image, distortion as one of the internal normal position elements is small, and is substantially ignorable in some cases. Namely, among the internal normal position elements, (D_2, D_4, D_6, N_1, N_2) are ignorable, and unknown internal normal position elements are only (f, X_C, Y_C). To calculate the internal normal position elements (f, X_C, Y_C), five or more reference points P_i three-dimensionally arranged are sufficient. When the eccentricity of the principal point from the image center can be ignored and distortion asymmetrical components and distortion fourth-order and sixth-order components can be ignored, the internal normal position elements to be calculated are (f, D_2), and four reference points are sufficient for internal orientation. As described above, when the number of internal orientation elements to be calculated is small, the number of reference points for internal orientation can be reduced, and this reduces the measuring labor and time.

[0054]

In the embodiment, explanation is given by assuming that the digital still camera 20 is arbitrarily disposed with respect to the surveying instrument 10, however, it is also possible that the digital still camera 20 is disposed at a position optically equivalent to the collimating telescope 17 of the

surveying instrument 10 by providing, for example, a tool for attaching the camera to the surveying instrument 10, and in this case, the number of unknown external orientation elements can be reduced, so that the number of reference points can be reduced. When the digital still camera 20 is disposed at a position optically equivalent to the collimating telescope 17 of the surveying instrument 10 and takes a survey image (when the projection center of the imaging optical system of the image pickup device is disposed at a position optically equivalent to the collimation origin of the collimating telescope), the horizontal angle and elevation angle can be directly calculated from image coordinates, and the processing becomes simple.

[0055]

Hereinafter, a modified example when the digital still camera 20 is disposed at a position optically equivalent to the collimating telescope 17 is explained with reference to Fig. 12. In this case, among the external orientation elements (X_O, Y_O, Z_O, ω, ϕ, κ), $X_O=Y_O=Z_O=0$. When the axis y' of the camera image coordinate system is disposed so as to correspond to the horizontal axis Lh of the surveying instrument 10, the survey coordinate system and the camera coordinate system are judged as identical to each other, so that when the surveying instrument 10 is collimated to an arbitrary survey point P_n within a survey

image (see Fig. 6), from the horizontal angle θh_o and the elevation angle θp_o as the initial collimation direction when taking the survey image, horizontal angle θh_n and elevation angle θp_n of the survey point P_n collimated in the surveying instrument 10, and image surface distance f of the imaging lens 22 (internal normal position elements are also used when distortion correction is necessary), the position (xp_n', yp_n') of the image point P_n' corresponding to the survey point P_n can be directly calculated as follows:

$xp_n'=f \bullet \tan(.h_n-.h_o)/Px+W/2,$

$yp_n'=f \bullet \tan(.p_n-.a_o)/Py+H/2.$ (9)

Therefore, when a collimation position (xp_n', yp_n') is specified on the survey image, the horizontal angle θh_n and elevation angle θp_n of the survey point P_n can be calculated reversely from the equation (9) as shown below, and collimation can be made by directing the surveying instrument 10 toward these angles.

$.h_n=\tan^{-1}(Px(xpn'-W/2)/f)+ .h_o$

$.p_n \ \tan^{-1}(Py(ypn'-H/2)/f)+ .p_o.$ (10)

[0056]

Fig. 12 is a flowchart of working procedures in this case.

First, in Step S601, the survey image and the survey coordinates are associated with each other by the single

photograph orientation processing of Fig. 2. At Step S602, for example, a survey point P_n is specified as a collimation point on the survey image by using the mouse 43, etc., (see Fig. 6), and a collimation mark is indicated at the specified position to indicate the collimation position. At Step S603, a position P_n' (xp_n', xp_n') on the survey image of the specified collimation point (survey point P_n) is substituted into the equation (10) to calculate collimation angles $(\theta h_n, \theta p_n)$, and collimation is made by directing the surveying instrument toward these. At Step S604, the indication of the collimated collimation point is changed (changed in color, shape, or size) and indicated on the survey image, and then the survey operation is ended.

[0057]

According to the modified example, an operator can visually confirm on the survey image that the collimation has been finished, and this further improves the collimating operability.

[0058]

As another modified example, survey operations when three-dimensional position data of the survey point to be collimated has already been known as design values such as a survey set point, or when three-dimensional position data of the collimation point has already been known as in the case

where a survey point that was surveyed once (three-dimensional data has been detected) is collimated again, are explained. When three-dimensional data of a survey point P_n to be collimated is known, it is also possible that the coordinates (X_n, Y_n, Z_n) of the survey point P_n are substituted for the Ri (X_{Ri}, Y_{Ri}, Z_{Ri}) in the equations (7) and (8) to calculate the horizontal angle θh_n and the elevation angle θp_n of the survey point P_n, and collimation is automatically made. Fig. 13 is a flowchart of operation procedures in this case.

[0059]

At Step S701, the survey image and the survey coordinates are associated with each other by the single photograph orientation processing of Fig. 2. At Step S702, a survey point (for example, a survey set point) whose three-dimensional coordinates are known is indicated on the survey image. An operator determines a collimation direction by instructing the survey point to be collimated on the survey image by using a pointing device such as the mouse 43 on the survey image. At Step S704, by substituting the three-dimensional coordinates of the specified survey point P_n into the equations (7) and (8), the collimation angles $(\theta h_n, \theta p_n)$ are calculated, and the surveying instrument is collimated toward these. At Step S705, the indication of the collimated survey point on the survey

image is changed (in color, shape, or size), and this survey processing is ended.

[0060]

Also in the modified example, the operability can be improved approximately as in the case of the above-described modified example since the end of collimation can be visually confirmed on the survey image. It is also possible that the indication mark of the survey point selected when instructing the survey point at Step S703 can be changed. In the case where a survey set point is used as the survey point, when the design coordinate system of the survey set point does not match the survey coordinate system of the survey site, the values of the survey set point in the design coordinate system are converted into values in the survey coordinate system. The reverse is also possible.

[0061]

In the embodiment, a surveying instrument is directed toward a collimation point R_i on a co-line LN_C with respect to a certain pixel, and survey coordinates (X_{Qi}, Y_{Qi}, Z_{Qi}) measured in this case are converted into image coordinates (x_{Qi}', y_{Qi}') of the survey image, and it is judged whether the image coordinates match the original pixel image coordinates (x_i', y_i'), however, it is also possible that this judgement is made by judging whether

the survey coordinates (X_{Qi}, Y_{Qi}, Z_{Qi}) and the survey coordinates (X_{Ri}, Y_{Ri}, Z_{Ri}) of the collimation point R_i match each other.

[0062]

In addition, in the embodiment, reference points are arbitrarily specified on a survey image by using a pointing device, however, it is also possible that a reference scale with known dimensions or reference marks that can be arbitrarily arranged are disposed in the image-taking range, and these are defined as reference points to determine external orientation elements. In this case, positions on the reference scale and reference marks are selected on the survey image by using the pointing device, etc. When the reference scale or reference marks are used, the positions of the reference points on the survey image can be automatically detected by using, for example, image processing.

[0063]

In the embodiment, the computer connected to the surveying instrument is used, however, it is also allowed that the surveying instrument or digital still camera is integrally provided with the functions of the computer of the embodiment. In the embodiment, a digital still camera is used, however, a video camera, etc., can also be used as long as a digital image can be obtained with the surveying instrument.

[0064]

[Effects of the Invention]

As described above, according to the invention, survey working efficiency can be improved. Furthermore, according to the invention, survey data obtained by a surveying instrument and image data obtained by a camera are easily and efficiently associated with each other, and automatic surveys based on the image data can be conducted.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1] is a block diagram generally showing the construction of the survey system of an embodiment of the invention;

[Fig. 2] is a flowchart of single photograph orientation processing in the survey system of the embodiment;

[Fig. 3] is a drawing conceptually showing the arrangement of the surveying instrument and the camera in the survey system of the embodiment;

[Fig. 4] is a drawing schematically showing the relationship between three reference points P_1, P_2, and P_3 and image points P_1', P_2', and P_3' at the imaging surface S;

[Fig. 5] is a flowchart of the program of the spatial resection backward intersection method for calculating the external orientation elements (X_O, Y_O, Z_O, ω, ϕ, κ) and camera internal normal position elements (f, D_2, D_4, D_6, N_1, N_2, X_C, Y_C) indicating

the position and inclination of the digital still camera;

[Fig. 6] is an example of a survey image when a survey region is determined;

[Fig. 7] is a drawing for generally explaining the principle of automatic survey of the embodiment;

[Fig. 8] is a flowchart of the program of the automatic survey processing operations of the embodiment;

[Fig. 9] is a flowchart of object point search processing to be executed at Step S303 of Fig. 8;

[Fig. 10] is a drawing showing the relationship between the collimating telescope and a survey coordinate system of the surveying instrument;

[Fig. 11] is a flowchart of unit co-line vector calculation processing to be executed at Step S401 of Fig. 9;

[Fig. 12] is a flowchart of operation procedures in the modified example in which the digital still camera is disposed at a position optically equivalent to the collimating telescope; and

[Fig. 13] is a flowchart of operation procedures when a horizontal angle θh_n and an elevation angle θp_n of a survey point P_n are calculated based on coordinates (X_n, Y_n, Z_n) of the survey point P_n and a survey is automatically made.

[Description of Symbols]

10 Surveying instrument

20 Digital still camera

40 Computer

[TITLE OF DOCUMENT] ABSTRACT

[ABSTRACT]

[OBJECT] To conduct an automatic survey of a point or region specified on a survey image of a survey site.

[SOLVING MEANS] A pixel (or region) to be surveyed is specified on a survey image taken by a digital still camera 20. A co-line LN_C that regulates collinear conditions with respect to the specified pixel is calculated from external orientation elements of the survey image for a surveying instrument 10. A collimation line (collimation direction) LN_O of the surveying instrument 10 is moved along the co-line LN_C and the surveying instrument 10 is collimated to a collimation point (R_1, R_2...) on the co-line LN_C to conduct a survey. A position of an object point Q_i measured when a survey is conducted toward the collimation point R_i is measured. When the position of the object point Q_i is a point on the co-line LN_C, the object point Q_i is regarded as an object point with respect to the specified pixel on the survey image. When a region is specified, these operations are performed for each pixel in the region.

[SELECTIVE DRAWING] Fig. 7

FIG. 1

11 Rangefinding portion

12 Angle measuring/angle controlling portion

13 System control circuit

14 Switch group

15 Display

16 Interface circuit

20 Digital camera

42 Recording medium

43 Mouse

44 Keyboard

45 Monitor

FIG. 2

S101 Take survey site image by DSC

S102 Specify reference points on image

S103 Survey and associate reference points by surveying instrument

S104 External orientation and internal orientation of DSC (spatial resection backward intersection method)

FIG. 3

Interface

FIG. 5

Spatial resection backward intersection method

S201 Set initial camera position and inclination and internal normal

position elements in successive approximation method

$(X_{GO}, Y_{GO}, Z_{GO}, \omega_G, \phi_G, \kappa_G)$

$(f_G, D_{2G}, D_{4G}, D_{6G}, N_{1G}, N_{2G}, X_{CG}, Y_{CG})$

S202 Calculate approximate image coordinates (xp_{Gi}', yp_{Gi}') of image point P_i' from current camera position, inclination, and internal normal position elements and survey coordinates (Xp_i, Yp_i, Zp_i) of reference point P_i

S203 Calculate merit function Φ

S204 Φ < predetermined value?

S205 Calculate correction amounts $(\delta X, \delta Y, \delta Z, \delta\omega, \delta\phi, \delta\kappa, \delta f, \delta D_2, \delta D_4, \delta D_6, \delta N_1, \delta N_2, \delta X_C, \delta Y_C)$ of camera position, inclination, internal normal position elements by least squares method

S206 Update camera position, inclination, and internal normal position elements

FIG. 6

Survey region

Object other than surveying item

FIG. 7

Object in survey region

FIG. 8

S301 Acquire survey region

S303 Acquire survey values of pixel (x_i', y_i')

S304 Store acquired survey values in memory

FIG. 9

S401 Calculate a unit co-line vector (r_{ix}, r_{iy}, r_{iz}) corresponding to image coordinates (x_i', y_i')

S402 Set $L=L_a$

S403 Calculate (θh, θp) from point (X_{Ri}, Y_{Ri}, Z_{Ri}) on co-line and direct TS toward these

S404 Conduct a survey with TS and acquire 3D coordinates (X_{Qi}, Y_{Qi}, Z_{Qi})

S405 Calculate image coordinates (x_{Qi}', y_{Qi}') corresponding to (X_{Qi}, Y_{Qi}, Z_{Qi})

S406 Do coordinates (x_{Qi}', y_{Qi}') match image coordinates (x_i', y_i')?

S407 Set (X_{Qi}, Y_{Qi}, Z_{Qi}) to 3D coordinates of image coordinates (x_i', y_i')

FIG. 11

S501 Calculate image coordinates (x_{Gi}', y_{Gi}') by delivering (X_O+r_{Gix}, Y_O+r_{Giy}, Z_O+r_{Giz}) to image coordinate calculation routine

S502 Merit function

$\Phi = (xi'-xGi')^2+(yi'-yGi')^2$

S505 Adjust δr_{ix}, δr_{iy}, δr_{iz} by the least squares method

S503 Φ < predetermined value?

S504 Set (r_{Gix}, r_{Giy}, r_{Giz}) as unit co-line vector

FIG. 12

S601 Single photograph orientation processing

S602 Specify survey point P_n to be collimated on survey image and indicate collimation mark at specified position

S603 Specify collimation position P_n' (xpn', ypn') on survey image, calculate horizontal angle θh_n and elevation angle θp_n from the coordinate values, and collimate toward these

S604 Change the indication (in color, shape, or size) of collimated survey set point on survey image and notifies the operator of collimation end

FIG. 13

S701 Single photograph orientation processing

S702 Indicate survey set point on survey image

S703 Specify survey set point P_n to be collimated on survey image

S704 Calculates horizontal angle θh_n and elevation angle θp_n from 3D coordinates (X_n, Y_n, Z_n) of survey point P_n by equations (6) and (7) and collimate toward these

S705 Change the indication (in color, shape, or size) of collimated survey set point on survey image and notifies the operator of collimation end

Fig.1

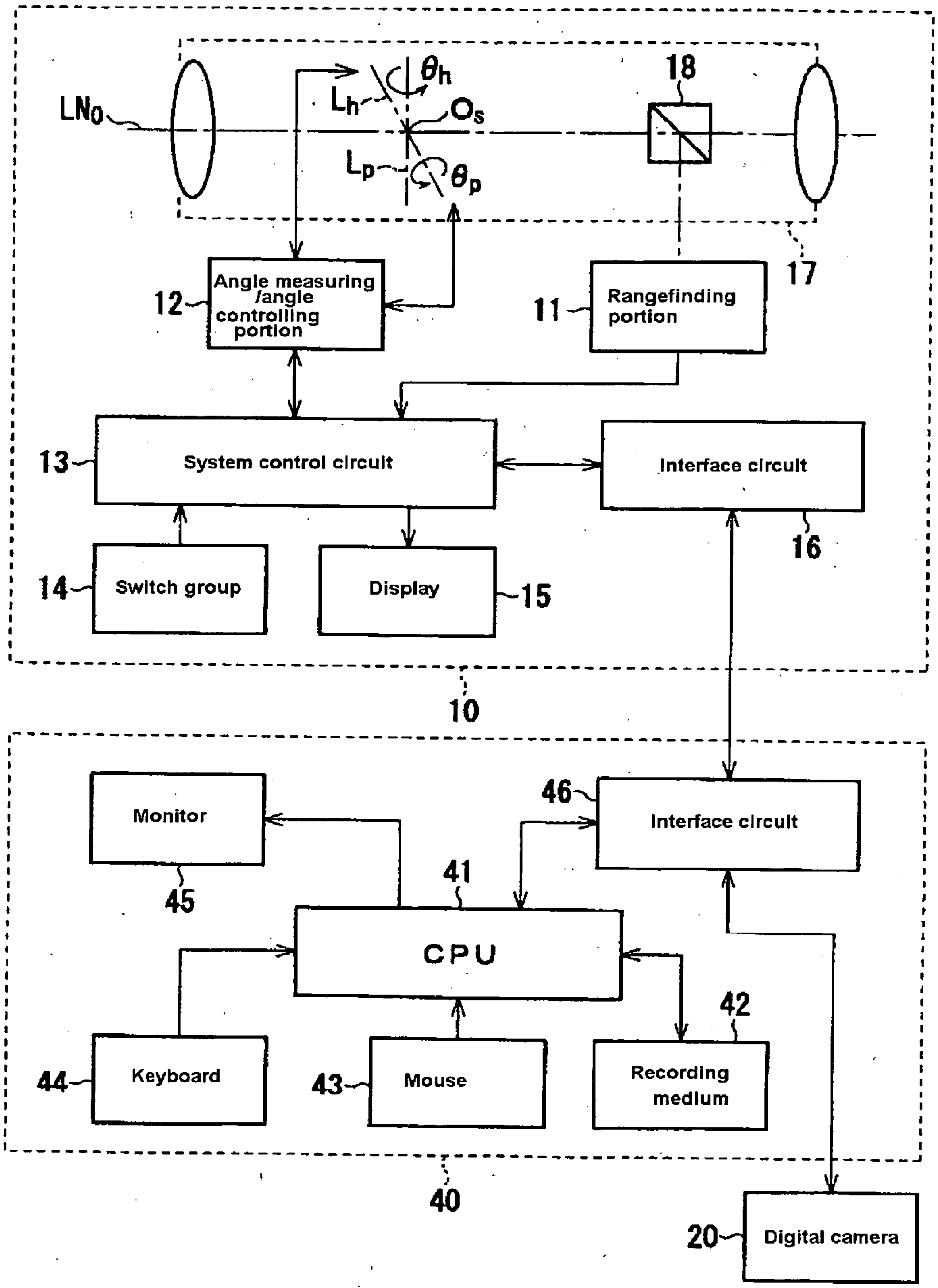

LN0
θh
Lh
Os
Lp
θp
18
17
12
Angle measuring /angle controlling portion
11
Rangefinding portion
13
System control circuit
Interface circuit
16
14
Switch group
Display
15
10
Monitor
45
46
Interface circuit
41
CPU
42
44
Keyboard
43
Mouse
Recording medium
40
20
Digital camera

Fig.2

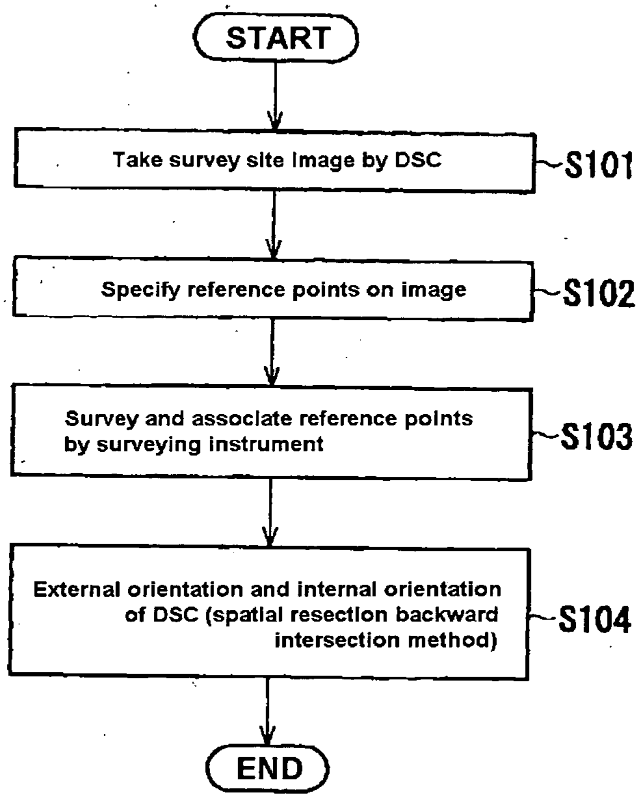

START
Take survey site image by DSC
S101
Specify reference points on image
S102
Survey and associate reference points by surveying instrument
S103
External orientation and internal orientation of DSC (spatial resection backward intersection method)
S104
END

Fig.3

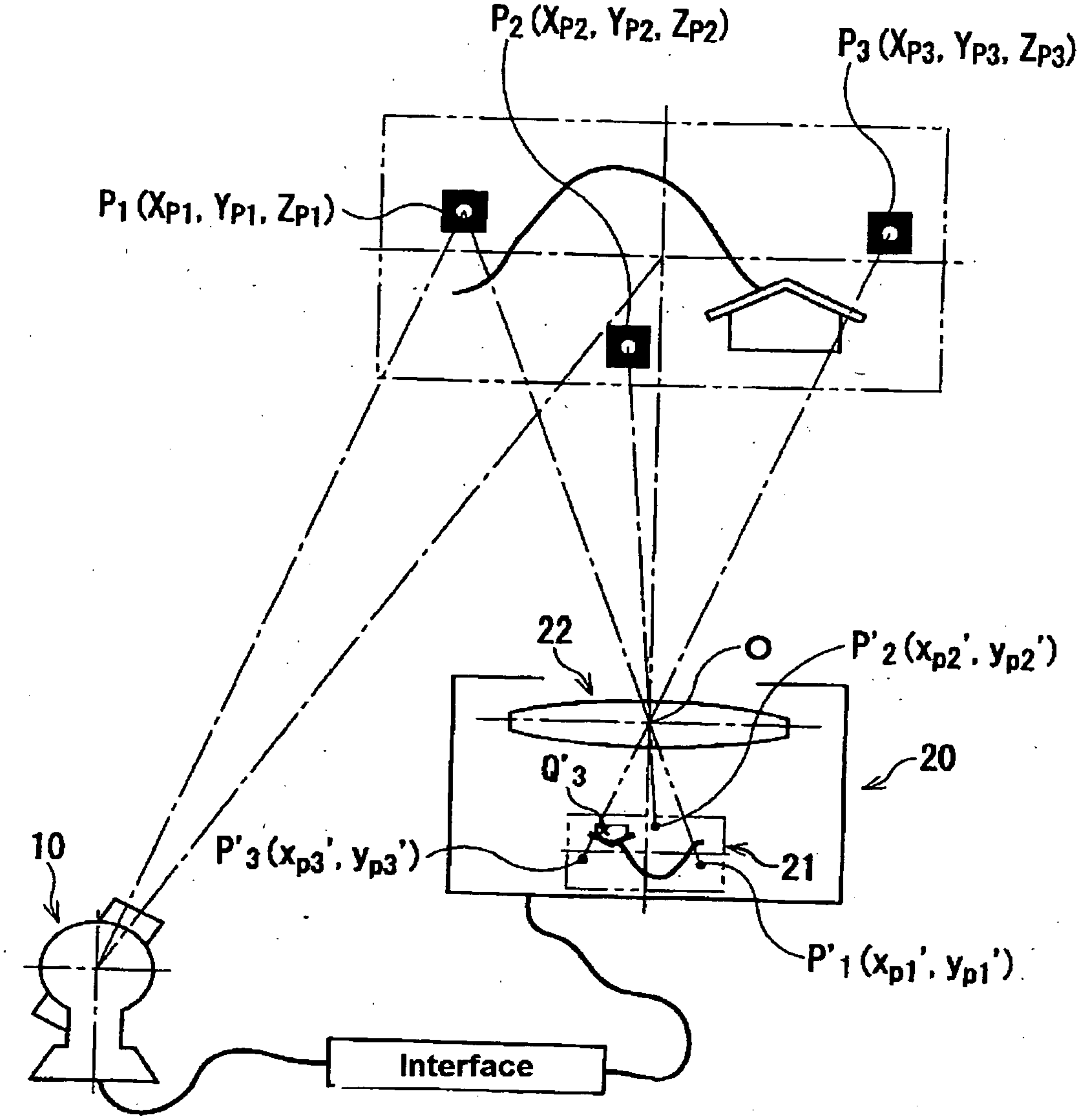
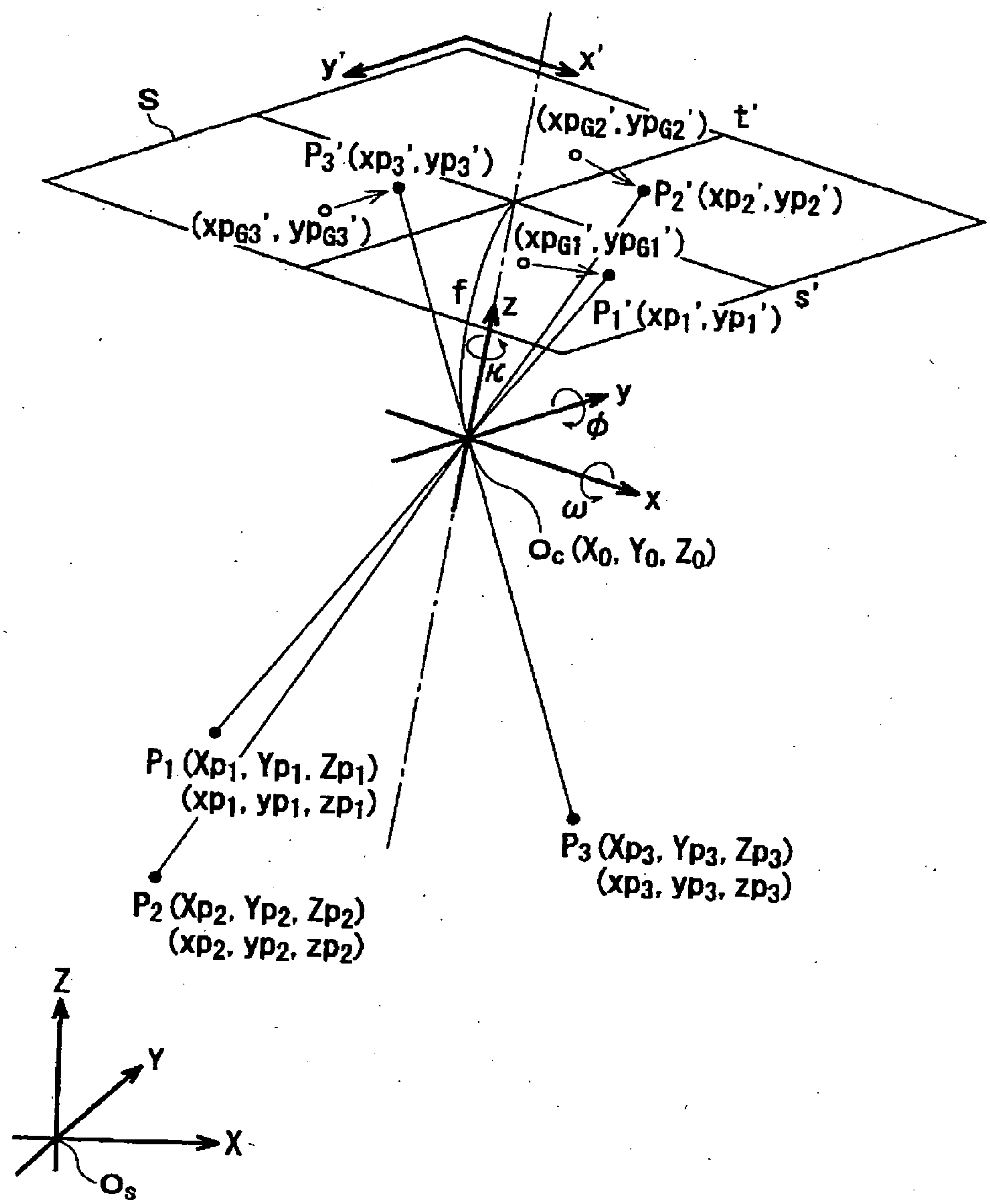

P2 (XP2, YP2, ZP2)
P3 (XP3, YP3, ZP3)
P1 (XP1, YP1, ZP1)
22
O
P'2 (xp2', yp2')
20
Q'3
10
P'3 (xp3', yp3')
21
P'1 (xp1', yp1')
Interface

Fig.4



y'
x'
S
t'
s'
(xp_{G2}', yp_{G2}')
$P_3'(xp_3', yp_3')$
$P_2'(xp_2', yp_2')$
(xp_{G3}', yp_{G3}')
(xp_{G1}', yp_{G1}')
$P_1'(xp_1', yp_1')$
f
z
κ
y
φ
x
ω
$O_c(X_0, Y_0, Z_0)$
$P_1(Xp_1, Yp_1, Zp_1)$
(xp_1, yp_1, zp_1)
$P_2(Xp_2, Yp_2, Zp_2)$
(xp_2, yp_2, zp_2)
$P_3(Xp_3, Yp_3, Zp_3)$
(xp_3, yp_3, zp_3)
Z
Y
X
O_s

Fig.5

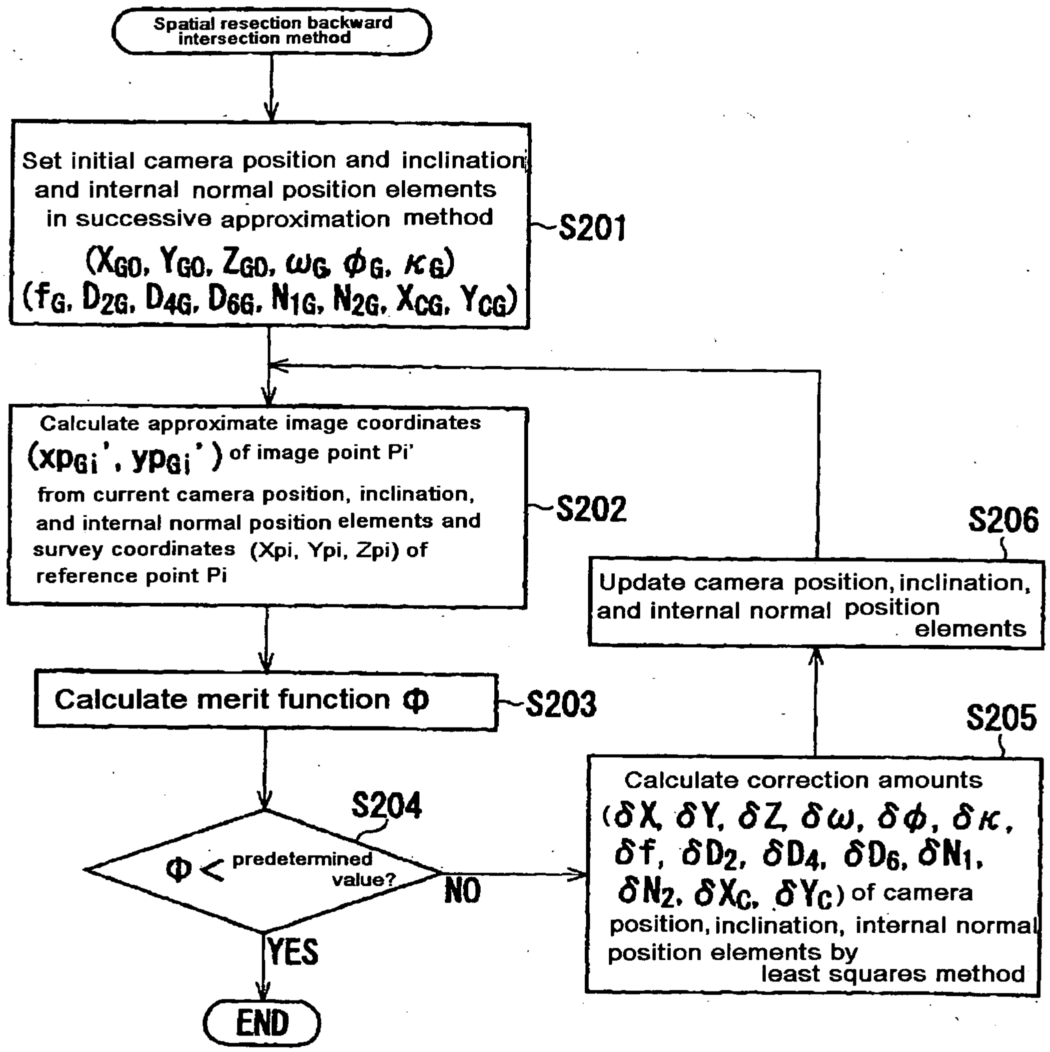
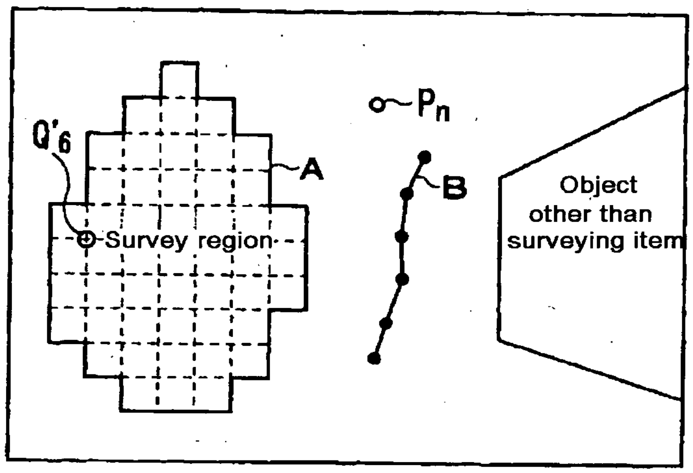
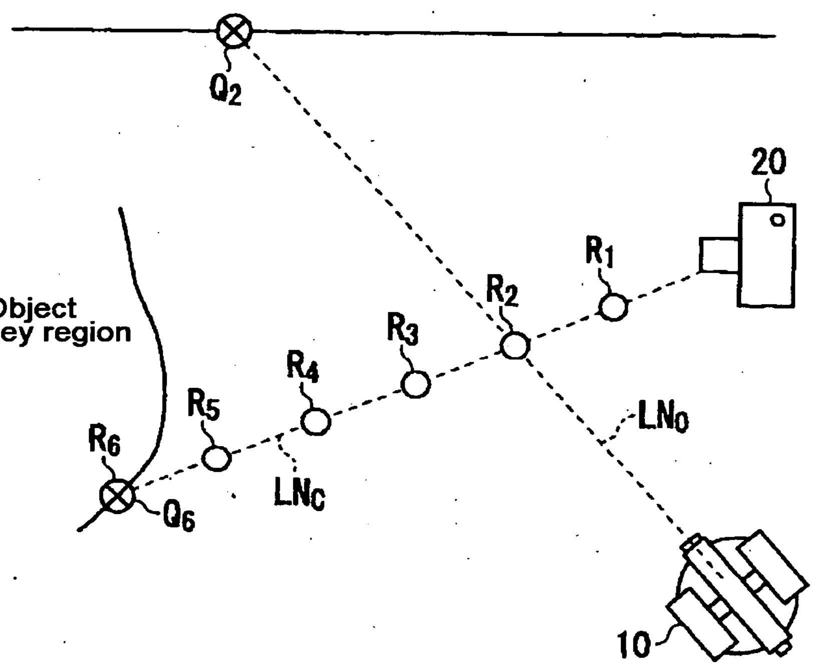

Spatial resection backward intersection method
Set initial camera position and inclination and internal normal position elements in successive approximation method
(XG0, YG0, ZG0, ωG, φG, κG)
(fG, D2G, D4G, D6G, N1G, N2G, XCG, YCG)
S201
Calculate approximate image coordinates (xpGi', ypGi') of image point Pi' from current camera position, inclination, and internal normal position elements and survey coordinates (Xpi, Ypi, Zpi) of reference point Pi
S202
Calculate merit function Φ
S203
Φ < predetermined value?
S204
NO
YES
END
Calculate correction amounts (δX, δY, δZ, δω, δφ, δκ, δf, δD2, δD4, δD6, δN1, δN2, δXC, δYC) of camera position, inclination, internal normal position elements by least squares method
S205
Update camera position, inclination, and internal normal position elements
S206

Fig.6



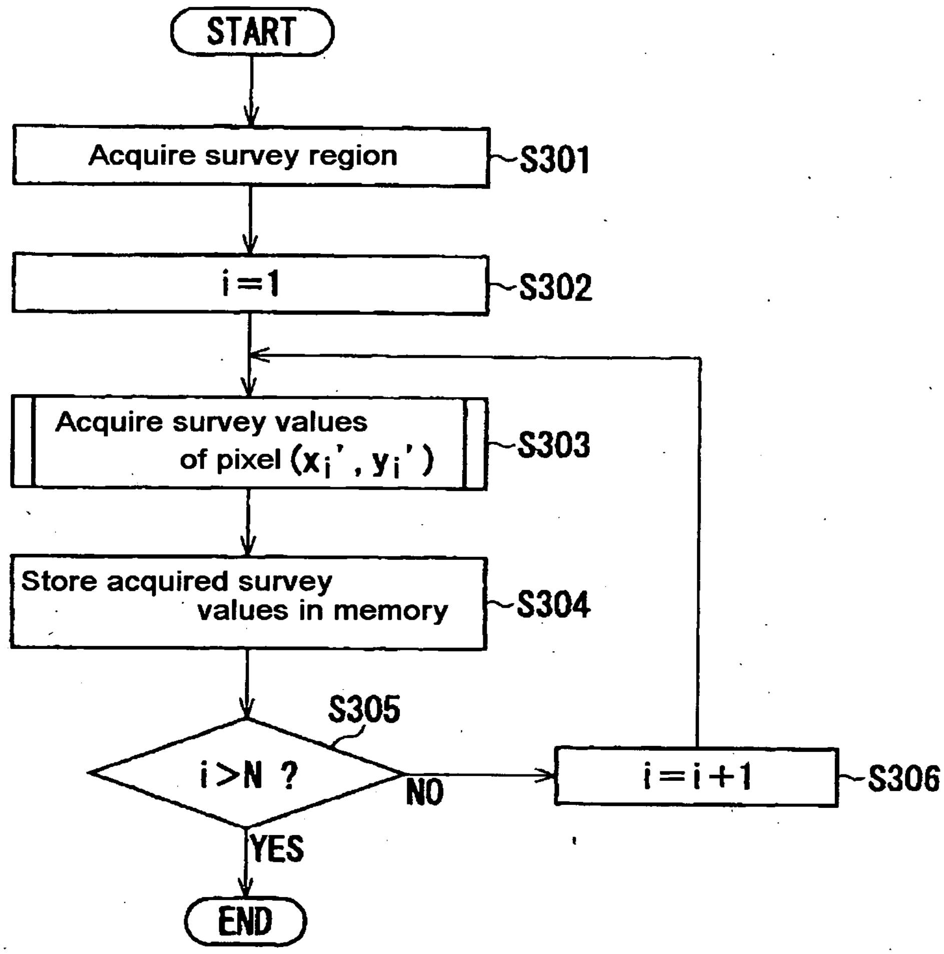
Q'6
A
Pn
B
Survey region
Object
other than
surveying item

Fig.7



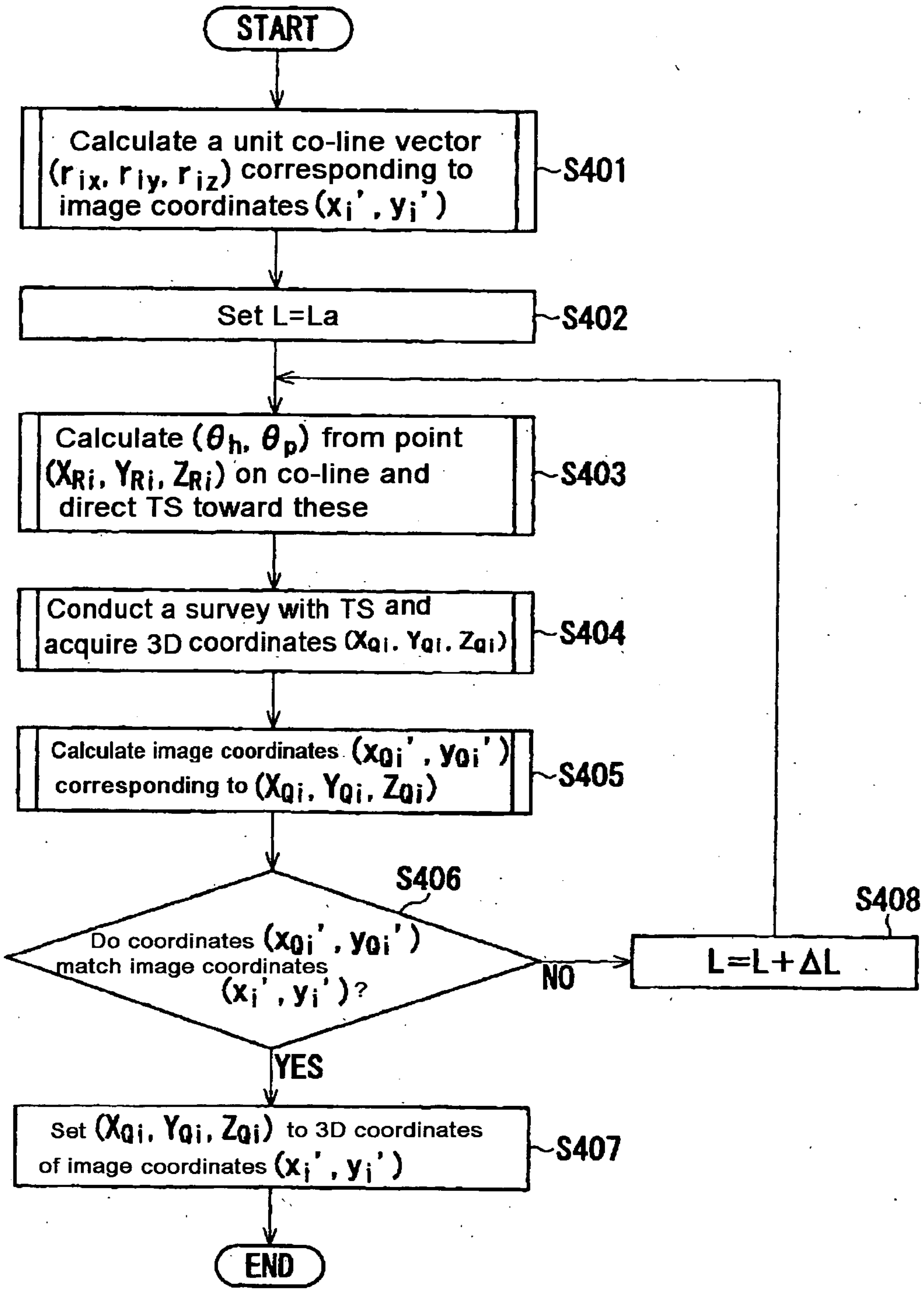
Q2
20
R1
R2
R3
R4
R5
R6
Object
in survey region
Q6
LNc
LN0
10

Fig.8



START
Acquire survey region
S301
i=1
S302
Acquire survey values of pixel (xi', yi')
S303
Store acquired survey values in memory
S304
S305
i>N ?
NO
YES
i=i+1
S306
END

Fig.9



START
Calculate a unit co-line vector (r_{ix}, r_{iy}, r_{iz}) corresponding to image coordinates (x_i', y_i')
S401
Set L=La
S402
Calculate (θ_h, θ_p) from point (X_{Ri}, Y_{Ri}, Z_{Ri}) on co-line and direct TS toward these
S403
Conduct a survey with TS and acquire 3D coordinates (X_{Qi}, Y_{Qi}, Z_{Qi})
S404
Calculate image coordinates (x_{Qi}', y_{Qi}') corresponding to (X_{Qi}, Y_{Qi}, Z_{Qi})
S405
S406
Do coordinates (x_{Qi}', y_{Qi}') match image coordinates (x_i', y_i')?
NO
S408
$L=L+\Delta L$
YES
Set (X_{Qi}, Y_{Qi}, Z_{Qi}) to 3D coordinates of image coordinates (x_i', y_i')
S407
END

Fig.10

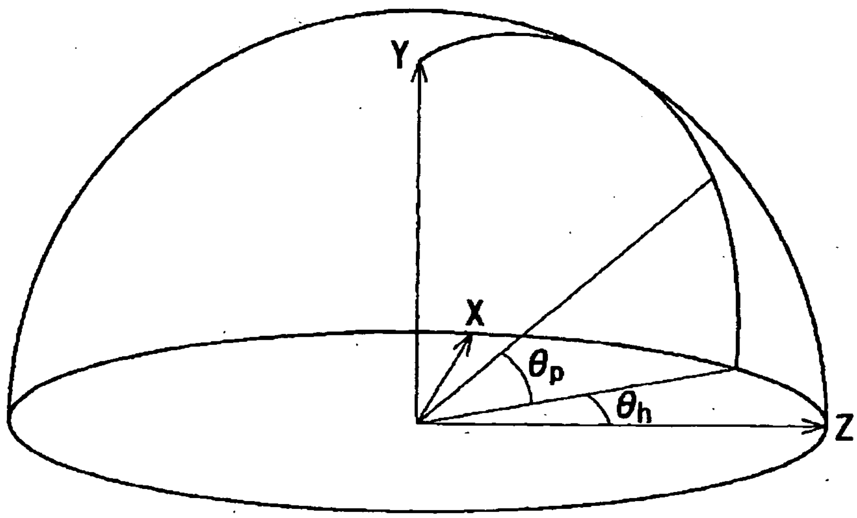


Fig.11

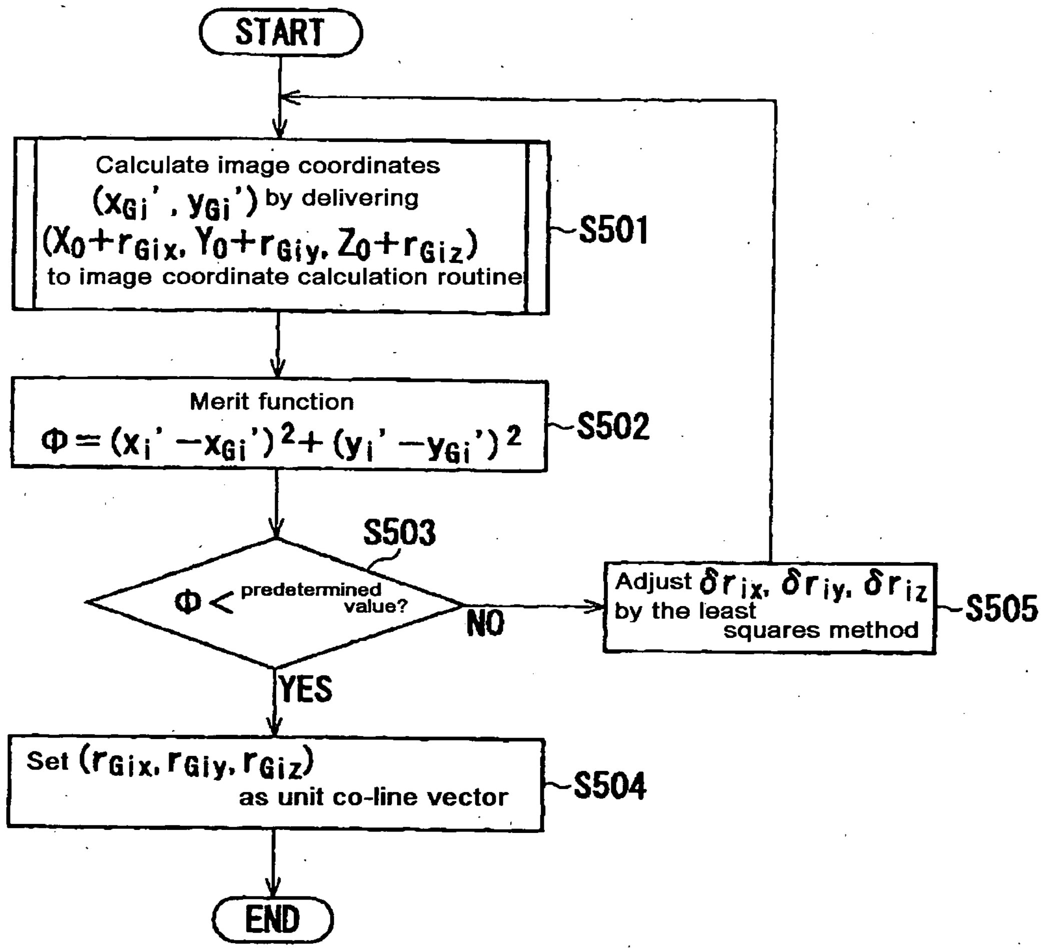
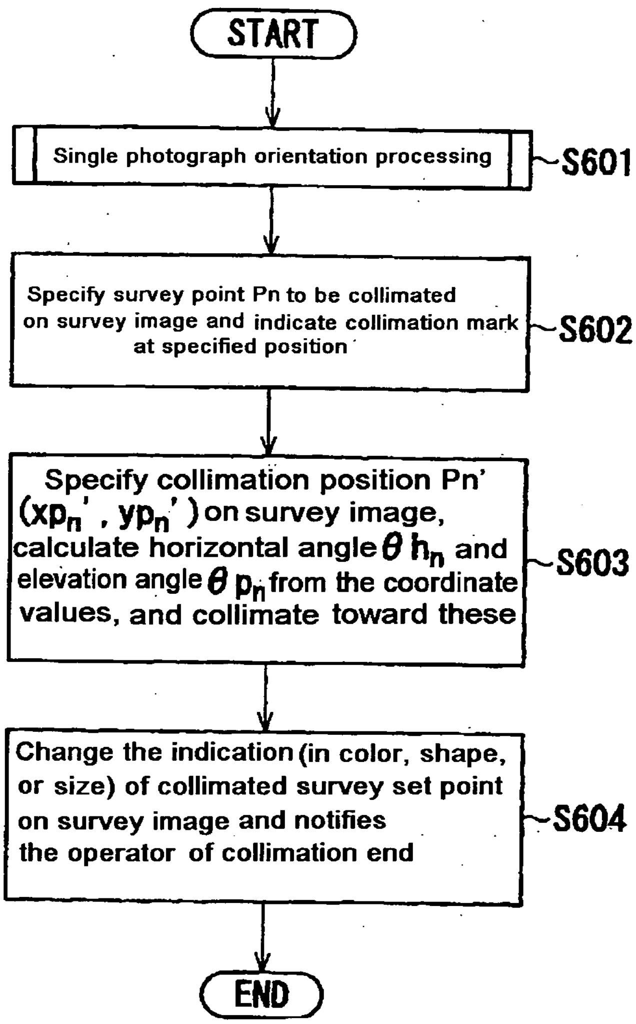
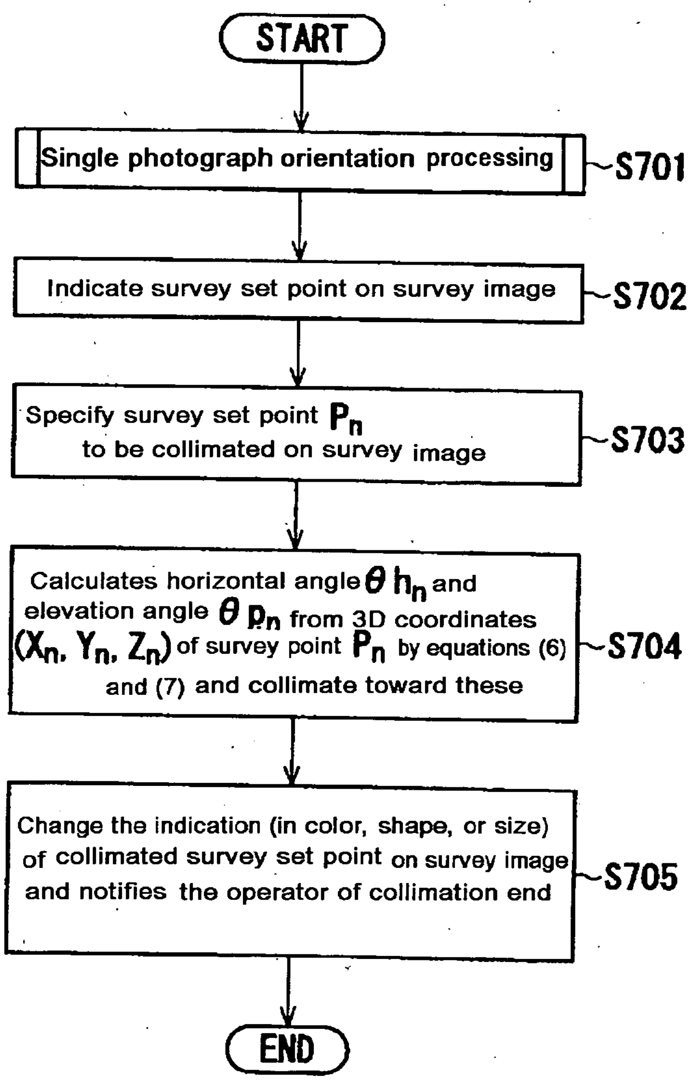

START
Calculate image coordinates
(x_{Gi}', y_{Gi}') by delivering
$(X_0+r_{Gix}, Y_0+r_{Giy}, Z_0+r_{Giz})$
to image coordinate calculation routine
S501
Merit function
$\Phi = (x_i' - x_{Gi}')^2 + (y_i' - y_{Gi}')^2$
S502
S503
$\Phi <$ predetermined value?
NO
Adjust $\delta r_{ix}, \delta r_{iy}, \delta r_{iz}$ by the least squares method
S505
YES
Set $(r_{Gix}, r_{Giy}, r_{Giz})$ as unit co-line vector
S504
END

Fig.12



START
Single photograph orientation processing
S601
Specify survey point Pn to be collimated on survey image and indicate collimation mark at specified position
S602
Specify collimation position Pn' (xpn', ypn') on survey image, calculate horizontal angle θhn and elevation angle θpn from the coordinate values, and collimate toward these
S603
Change the indication (in color, shape, or size) of collimated survey set point on survey image and notifies the operator of collimation end
S604
END

Fig.13


START
Single photograph orientation processing
S701
Indicate survey set point on survey image
S702
Specify survey set point P_n to be collimated on survey image
S703
Calculates horizontal angle θh_n and elevation angle θp_n from 3D coordinates (X_n, Y_n, Z_n) of survey point P_n by equations (6) and (7) and collimate toward these
S704
Change the indication (in color, shape, or size) of collimated survey set point on survey image and notifies the operator of collimation end
S705
END